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THE CORRIDOR INTEGRATED WEATHER SYSTEM (CIWS)

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1. INTRODUCTION†

The FAA Operational Evolution Plan (OEP) identified en route severe weather as one of the four problems that must be addressed if the U.S. air transportation system is to alleviate the growing gap between the demand for air transportation and the ability of the system to meet that demand.

Convective weather in highly congested airspace is of particular concern because many of the delays arise from these corridors. For example, rerouting aircraft around areas of actual or predicted weather can be very difficult when one must be concerned about controller overload in the weather free sectors. When major terminals also underlie the en route airspace, convective weather has even greater adverse impacts.

The principal thrust to date in addressing this problem has been "strategic" collaborative routing as exemplified by the "Spring 2000" and "Spring 2001" initiatives. However, success of the strategic approach embodied in these initiatives depends on the ability to accurately forecast convective weather impacts two or more hours in advance. Limitations in the forecast accuracy necessitate development of a companion “tactical” convective weather capability [Evans, 2001].

In this paper, we describe a major new FAA initiative, the Corridor Integrated Weather System (CIWS). The objective of this project, which is currently in the concept exploration phase, is to improve tactical convective weather decision support for congested en route airspace. A real time operational demonstration, which was begun in July 2001 in the Great Lakes corridor, will be extended to the Northeast corridor in 2002. In the sections that follow, we describe the operational needs that motivated the CIWS initiative, the technology under investigation, the concept exploration test bed and summer 2001 operational experience, and the near term plans for the CIWS concept exploration.

2. OPERATIONAL NEEDS AND TECHNOLOGICAL APPROACH

The objective of the CIWS is to improve safety and efficiency when there is severe en route convective weather. CIWS meets this objective by providing en route controllers, en route and major terminal traffic flow managers, and airline dispatch with accurate, automated, rapidly updating information on storm locations and 0-2 hour forecasts of storms, so that they can achieve more efficient tactical use of the airspace. These “tactical” traffic flow management products will complement the longer-term (2-6 hr) national CCFP forecasts that are also needed for flight planning and traffic flow management.

Current system deficiencies

There are a number of deficiencies in the current tactical en route support capability. En route controllers today do not have accurate, timely information on locations of significant storms. The FAA has had a long standing plan to provide NEXRAD composite reflectivity mosaics to the controller displays, in addition to presenting the information on the dedicated weather and radar processor (WARP) displays at traffic management unit and area supervisor positions in an en route center (ARTCC). However, there are concerns over precipitation intensity data anomalies (e.g., AP clutter, "bulls eyes") currently found in the WARP products, update rates/latency of the precipitation products, and the vertical layers by which three-dimensional storm information is presented [Schwitz, 2000]. These problems are not unique to WARP. Traffic management units obtain commercial vendor mosaics of NEXRAD surface tilts and composite reflectivity. These mosaics have many of data quality and update rate/latency problems observed in WARP products, since they all rely on the current NEXRAD "narrow band" products. (Data quality edited vendor mosaics, when available, can have greatly increased latency.)

Existing operational forecast products within en route airspace are limited. Most en route weather decision support systems show only current and past storm locations. The Aviation Weather Center provides two products: the National Convective Weather Forecast (NCWF) with one-hour forecast contours, and the Collaborative Convective Weather Forecast Product (CCFP) 2,4, and 6-hour predictions that are updated every four hours. The NCWF uses as its input a vendor-supplied vertically integrated liquid water (VIL) mosaic, augmented with cloud-to-ground lightning

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stroke "equivalent" precipitation and the "scale separation" tracking concept used in the Terminal Convective Weather Forecast (TCWF) [Wolfson, 1999]. Since the intent of the NCWF is to focus on large areas of convective activity, forecasts are not provided for small convective cells (e.g., those with areas less than 512 sq km) and the approximate spatial resolution of the smoothed forecast contours is 8 km. Hence, smaller cell complexes, which can be of concern for congested airspace, do not have NCWF forecasts.

Forecasting the time at which gaps in squall lines and between cells will "fill in" is critical for tactical operations. Crucial to the accuracy of these forecasts it the ability to forecast new storm development. A major limitation in tackling this problem at the national or regional scales is the lack of surface boundary layer wind information. The NEXRAD radars are spaced approximately 230 km apart; however the effective range at which surface frontal features such as gust fronts are observed is limited to about 80 km from each NEXRAD over flat terrain [NRC, 1995]. Hence, a large fraction (over half) of the region that is nominally covered by NEXRADs does not have high quality surface wind coverage.

Situational awareness between various decision makers also could be improved. The NCWF and CCFP will be available to all key decision makers via the ETMS system shortly. However, neither TRACONs nor airline dispatch currently has access to the WARP products being used by en route TMUs and controllers.

Technological options for improving en route tactical support

There are three key steps to improving forecast capability:

1. Better weather sensing, including an improved update rate for the information,
2. Improved algorithms for creating the storm severity products and forecasts, and
3. Common situational awareness between all of the key users.

It is essential to use <u>both</u> terminal and en route weather sensors to create the improved convective weather products for congested en route airspace [just as the Integrated Terminal Weather System (ITWS) has been very successful at using en route sensors to improve terminal operations)]. To significantly improve the effective rate at which the full surveillance volume is scanned, both ASR-9s and ARSR-4s[1] can be used to provide a weather product with a volume update of at least once per minute. As will be shown, the ASR9s have a very dense coverage in congested corridors. Additionally, the ASR-11s when deployed will further improve the region that is rapidly scanned. This much higher data rate is particularly important when there is airmass convection and/or "explosive" line storm development.

The ability to predict the development of new cells in areas that are being used by en route traffic is critical for improved operations. A key factor in convective initiation is measurement of surface wind convergence. By using both NEXRADs and TDWRs, it will be possible to do a much better job of surface convergence detection than with NEXRAD alone (especially near major terminal complexes such as New York/Philadelphia, the Washington DC area, near Chicago and in southern Ohio).[2]

Another important issue is the algorithms by which the various sensor data are processed and integrated. The ITWS algorithms for comparing the various weather radar sensors to remove data artifacts such as AP [Evans and Ducot, 1994] can clearly be adapted to en route surveillance. Since NEXRAD is a key sensor for en route surveillance, the CIWS concept exploration uses full resolution base data from the NEXRAD to create intermediate and final products (e.g., reliably discriminating between AP and valid weather returns is very difficult using the current NEXRAD coarsely quantized "narrow band" base products).[3] For NEXRAD or TDWR, there are a number of options for the precipitation product [e.g., composite reflectivity, surface tilt reflectivity, vertically integrated liquid water (VIL)]. The concept exploration phase is focusing on VIL [Robinson, et. al, 2002] as a better indicator of storm severity and new growth that is less susceptible to AP and other data anomalies than other precipitation options.

Since the congested corridors cover very large expanses, it is clear that radar mosaics will be necessary. One of the important issues in creating a NEXRAD mosaic is accounting for the motion of storms in the mosaic operation. Since NEXRADs typically have volume scan times of five to six minutes and scan asynchronously, adjacent NEXRADs can observe a given storm at times that differ by as much as six minutes. If the storms are moving at 100 km per hr (not uncommon in the spring or fall), the observed location of a given cell can differ by as much as 10 km between adjacent radars. Hence, if no allowance is made for the motion, the spatial extent of a storm will be overestimated in the direction in which they are moving by considerable distances and the apparent location of the storm can change dramatically in short periods of time[4]. To reduce these artifacts, the CIWS advects the

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[1] The ARSR-4s are long range L-band surveillance radars positioned around the perimeter of the country. They have a 6 VIP level output which is analogous to the terminal ASR-9 "weather channel". To date, the FAA has not yet made use of the ARSR-4 6-level precipitation product.

[2] It is also possible that the ASR9 WSP gust front product may be useful for surface convergence detection.

[3] See section 5 for a discussion of the use of NEXRAD base data for an operational CIWS.

[4] Particularly if the product used is a mosaic of surface tilts.

measured precipitation products from each of the radars prior to the mosaic operation.

It is also very important to be able to identify precisely which routes (especially those feeding into and out of the terminals) are currently and will be impacted in future by adverse weather. Hence, for the CIWS, it is important to have at least 1 km spatial resolution near major terminals with no poorer than 2 km spatial resolution over the remainder of the coverage volume.

Applicable contemporary automated forecast product technology is described in [Dupree, et al. 2002] and [Boldi, et al. 2002]. Key features in these algorithms are:

- Storm growth and decay are explicitly determined such that the resulting forecasts incorporate growth and decay trends,
- Use of satellite data in conjunction with radar data,
- Scale separation technology to regionally classify precipitation by type so as to optimize performance on a regional basis,
- Explicit consideration of small scale forcing (e.g. storm initiation, growth, and dissipation) during the 0 - 60 min forecast range and larger scale forcing (e.g. fronts) for the 60 - 120 min forecast range, and
- Real time metrics for the forecast accuracy that assist the user in estimating the forecast utility as a function of forecast time and location within the CIWS domain.

Finally, it has become clear from the ITWS experience that there needs to be common situational awareness between the key FAA facilities and the airlines. For these congested corridors, displays need to be provided at key ARTCCs, the ATC System Command Center (ATCSCC), and the major TRACONs. Airline systems operations centers must have access to the same CIWS products. This is being done for ITWS via servers on the Internet and CDMnet [Maloney, et. al, 2002].

3. CIWS CONCEPT EXPLORATION TESTBED

A real time test bed for generating and distributing the experimental CIWS products was developed in 2000-02. Figure 1 shows the sensors used for the summer 2001 tests as well as the additional sensors that will be used in the summer 2002.

Access to the full resolution NEXRAD base data was accomplished using a compression server developed under the CRAFT project [Drogemeier 2001] in conjunction with the Local Data Manager (LDM) software package developed by Unidata. Access to the ASR-9 data is accomplished using the ASIS card interface used in the ITWS test beds, and the ARSR-4 data access will utilize a system developed by the NWS.

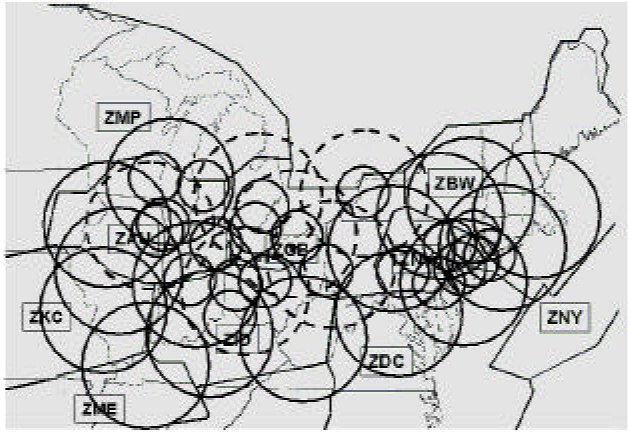

Figure 1. Dashed circles are coverage of the NEXRAD sensors used in the 2001 testing. The small solid circles are the ASR-9 sensors to be used in 2002; the large solid circles are additional NEXRAD sensors for the 2002 testing.

Given the very large number of sensors, wide area of operation and the need to be able to rapidly expand the system as needed, the communications infrastructure is a very important feature of the CIWS test bed. In contrast to the ITWS demonstration systems in which dedicated point-to-point links were used, the CIWS testbed has successfully used a frame relay network. At each sensor or external user location, there is a local line to the frame relay packet switched network. Redundant T1 links between the frame relay network and the real time product generation center at Lexington MA have provided essentially 100% availability of frame relay communications since the system commenced real time operations in May of 2001.

A network of COTS Unix and Linux workstations, located in Lexington, MA, provides the compute power for data ingest and product generation. To support the development of new algorithms, the system is designed to be modular and flexible. Algorithms can be assigned to individual workstations or sets of workstations to limit resource contention issues. Data are shared between algorithms by means of TCP/IP data streams and shared disks. Additional resources can easily be incorporated into the system by including new workstations in the network. Hardware failures can be easily and quickly resolved using hot spares.

System monitoring is done at a number of levels. First, each of the input data sources (i.e. NEXRAD base data and ASR-9 data) is monitored using simple scripts to alert personnel to data outages, via audio messages and email pages. Additionally, analysis displays show base data images, as well as intermediate products (e.g., VIL), to allow for human interpretation. Finally, the remote user displays are monitored so that communications failures, hardware, and software failures are detected quickly. The Lincoln site personnel are notified of any such failures automatically.

These design features result in a highly available, flexible system, freeing algorithm developers to concentrate on product concepts and algorithm design.

A 1-km spatial resolution VIL mosaic with motion compensation[5] was used as the CIWS precipitation product in 2001. The basic ITWS correlation tracker was used to estimate the cell motions and storm extrapolated positions.

The TCWF technology was adapted to provide an initial Regional Convective Weather Forecast (RCWF) in which scale separation tracking was accomplished on a local basis within the overall CIWS domain. Both critical success indices (CSI) scores and the ability to overlay forecasts for the current time over the current precipitation products were used to provide a real time indication of RCWF accuracy.

The CIWS concept exploration displays needed to rapidly evolve. The "display engine" for this display is an adaptation of the ITWS Java based web server display (Maloney, et al). Figure 2 shows the CIWS operational product display used in the 2001 operational demonstration.

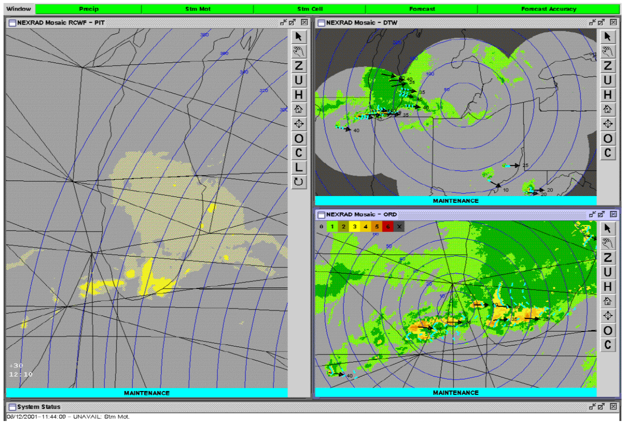

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Figure 2. 2001 CIWS display. The left hand window is an animation of the past weather and the RCWF predictions. The upper right window is a NEXRAD VIL mosaic. The lower right window shows storm cell motion vectors and extrapolated positions on a zoomed in version of the NEXRAD VIL mosaic.

4. OPERATIONAL EXPERIENCE IN 2001

Operational use of the CIWS NEXRAD VIL mosaic commenced on 10 July 2001, with displays at the Cleveland, Chicago and Indianapolis En Route Centers (ZOB, ZAU, ZID). Displays at the NY TRACON and the Command Center were added in early August, with airline access to the CIWS WWW server beginning at the end of August. Lincoln staff provided user training via presentations, demonstration situation displays, and a users manual that drew heavily on the corresponding ITWS material.

Significant ATC impacts (e.g., airport ground stops and significant en route delays) occurred on 37 days in the period 7/10/01 to 9/30/01, with level 5 convection somewhere in the CIWS coverage area (see fig. 1) on 44 days. On 45 days, storm radar tops exceeded 38 kft.

The regional convective weather forecast (RCWF) was found to be particularly useful, especially when convection developed rapidly in congested areas not anticipated by the CCFP.

Since the users had been using WARP precipitation products for a number of years, acceptance of the new VIL mosaic was somewhat slower to occur since there were many more WARP displays than CIWS displays in the TMU area. This identified a need to provide much more detailed training on the performance differences between VIL and the current WARP precipitation products (see, e.g., [Robinson, 2002]).

Perhaps the most interesting operational finding was that the en route facilities were far less likely in 2001 to take advantage of tactical opportunities than had been the case at the ITWS facilities using similar products. This difference reflects several factors: multiple facility coordination and flight plan amendment are much more important and difficult in the en route airspace; lack of familiarity with the CIWS products, the lack of explicit storm growth/decay information in the forecasts, and a less than optimal means of depicting storm height information [the 2001 CIWS display used the ITWS approach wherein users click on a cell to obtain tops information].

5. PLANS FOR 2002

Based on the feedback from the CIWS FAA/airline users group held in February 2002, many significant changes to the CIWS demonstration real time products are planned. These new thrusts include:

1. Fully automated 2-hour forecasts that have explicit estimates of storm growth and decay through joint use of radar and satellite data [Boldi, et. al, this conference]. Small scale forcing (e.g. storm initiation, growth, and dissipation) is the principal focus for the 0 - 60 min forecasts, with larger scale forcing (e.g. fronts) being used to generate the 60 - 120 min forecasts. Each of the forecasts is advected with its own motion field. Users will be able to see explicitly regions where storms are growing and decaying.

   The 2-hr forecast provides the users with two basic products. The first is a movie loop showing the past hour of weather and the forecast maps for the next two hours at 15-minute increments. The forecast maps depict regions of low, moderate, and high probability of NWS Level-3 (or greater) convective weather, and explicitly portray the predicted weather regions. The second product is the performances of the 30 and 60 minute forecast

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[5] The ITWS correlation tracker was used to determine motions of cells for each radars so that the various cell positions could be advected prior to use of the ITWS ASR-9 mosaic algorithm.

horizons; as characterized by CSI scores and, the current weather with past forecasts for the current time as contour overlays.

2. Extending the CIWS coverage to include the Northeast corridor by taking advantage of the existing coverage provided by the New York ITWS demonstration system (see fig. 1),
3. A dramatic increase in data rate through a combined mosaic of ASR-9 and NEXRAD VIL data in which the ASR-9 regions update once per minute with the “background” NEXRAD VIL mosaic updating every 2.5 minutes. The regions of ASR-9 coverage will be distinguishable from the regions of NEXRAD VIL mosaic via differences in the background colors (see fig. 3),
4. An improved depiction of storm radar tops to facilitate identifying regions where aircraft can fly over the storms [Rhoda, 2002]. Echo tops for many of the storms will be provided as an user option overlay for the NEXRAD VIL and ASR-9/NEXRAD VIL mosaics,
5. GOES satellite data as an optional background for the NEXRAD VIL mosaic, and
6. Expanded real time access to the CIWS products for major TRACONs (Chicago, New York, Detroit, Pittsburgh, Cincinnati, and Cleveland), ARTCCs (Boston and Washington) and airlines.

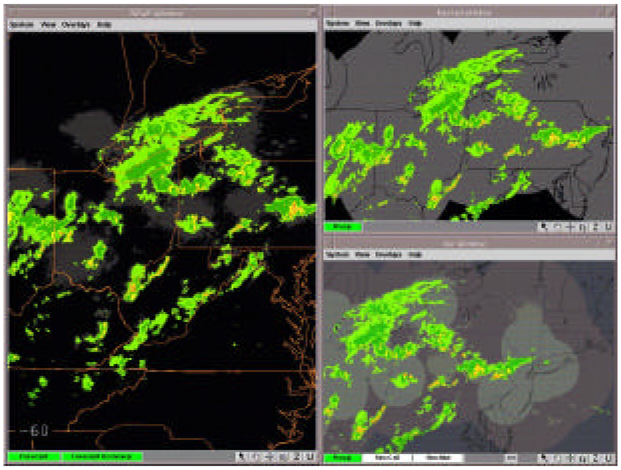

Figure 3. Planned 2002 CIWS display. The left window is the RCWF 2-hr Forecast loop (-60 to +120 min in 15 min increments.) The upper right window is the NEXRAD VIL mosaic with redesigned window design. The lower right window is the new ASR-9 mosaic, (small light grey circles) with the high resolution NEXRAD mosaic as background.

Offline, there will be an investigation of the integration of the CIWS weather products with contemporary air traffic automation systems (e.g., URET and "Direct To"), which can facilitate flight plan amendment coordination, and with traffic flow management systems (e.g., ETMS/CRCT) to permit "what if" assessment of the traffic loading from re routes.

A detailed delay reduction benefits assessment will be carried out using the methodology that has been successfully used for ITWS benefits assessment [Allan, et. al., 2000]: a combination of user interviews and flight track analysis will be used to determine how often certain key decisions (e.g., use of gaps in squall lines, identifying opportunities for closed routes to be reopened due to storm decay and/or aircraft flying over storms, increasing departure rates from major terminals, etc.) have benefited from the use of CIWS -- above and beyond what would have been possible with the “baseline” weather decision support systems of WARP and ETMS.

6. IMPLEMENTATION OF CIWS FUNCTIONALITY IN THE NAS ARCHITECTURE

The long term plan is to provide the CIWS products on existing en route, national and terminal decision support systems such as WARP, ITWS and ETMS (The dedicated displays used for the 2001-02 demonstrations are being used only to permit a rapid prototyping evaluation.) One of the major issues to be addressed in the architecture study will be the system for product generation. WARP has access to NEXRADs and other data that would be used in a CIWS. However, up to this point, the WARP has had fairly minimal automatic product generation capability (in contrast to the ITWS). Hence, there are issues of expandability and architecture for a WARP product generator that would need to be examined in detail. Another important architecture feature will be the allocation of processing capability between the CIWS product generator and the ITWS and NEXRAD product generators. For example, an ITWS associated with a large TRACON mosaics ASR-9s. Should the CIWS mosaic the ITWS mosaics along with ASR-9s not associated with an ITWS or, should the CIWS mosaic all ASR-9s “from scratch”? Similar issues arise for the use of TDWR gust front information for storm convective initiation. In addition, there is the question of whether CIWS should access base data (as done in the CIWS demonstration systems) versus using the output of the NEXRAD ORPG. Finally, there is the issue of communications architecture for the CIWS. The frame relay used for the demonstration system has worked well, but there are several alternative communications systems already in use by the FAA, which need to be considered.

There are several important operational usage issues that need to be examined. Perhaps the most important questions are how to characterize the uncertainty in the CIWS forecasts as the forecast time extends so as to best facilitate effective traffic flow management, and how to arrive at "seamless" guidance between the CCFP forecasts and the CIWS forecasts. The spatial coverage of the CIWS is also an important issue: some portions of the current CIWS coverage have significant congestion due to flights from regions not currently covered (e.g., the area to the south of Washington DC). Extending the CIWS coverage to the south and west of the 2002 coverage, while still maintaining the product capabilities, will be difficult due to the lack of terminal sensors in a number of key regions. Another issue is whether the ASR-9 (and ARSR-4) high update rate mosaic should be considered as a candidate for en route controller displays so as to address the NEXRAD layer composite reflectivity mosaic data rate and latency concerns. For systems such as ETMS, it would be desirable to have the NCWF and CIWS forecasts mosaiced so that the users would have the best available forecast available in each region on a "seamless" basis.

7. SUMMARY

Reducing the very rapid increase in ATC delays that occurred in the 1999-2001 time frame will require improving tactical decision support for severe en route convective weather; particularly in highly congested corridors. The CIWS is a major initiative to provide significant enhancements in tactical operations in these corridors through improvements in short term forecasts, storm severity information, precipitation product data rate, storm tops information, and common situational awareness between the Command Center, ARTCCs, major TRACONS and airline dispatch. A major real time demonstration of these capabilities will take place in 2002 in the Great Lakes and Northeast corridors.

Additionally, it will be necessary to interface these enhanced products to air traffic automation and traffic flow management systems that will reduce the workload associated with making “tactical” adjustments as the convective weather evolves.

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